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IV.

THE CONSTITUTION OF THE ATOM.

By HAROLD A. WILSON, F.R.S.

(Read April 22, 1911.)

According to Sir J. J. Thomson's theory[1] atoms may be regarded as rigid spheres of positive electricity containing negative electrons which can move about freely through the positive charge. The total negative charge on the electrons in an atom is equal to the positive charge on the sphere. This theory has many advantages over the theory of Sir J. Larmor, who regards atoms as systems of positive and negative electrons in rapid motion. In the first place the sphere of positive electricity provides a rigid and stable foundation which is lacking in the other theory and which seems very necessary to explain the extraordinary stability of atoms. It is difficult to see how Sir J. Larmor's atoms could possibly survive the shocks of continual violent collisions with other atoms.

Sir J. J. Thomson's theory has also the great advantage that it explains the fact that only negative electrons can be isolated and that positive electricity is always associated with atoms or molecules of matter.

It also explains the fact deduced from the Zeemann effect that spectral lines are emitted by vibrating negative electrons and not by positive electrons. It is consistent with the fact that atoms can lose a few negative electrons without their identity being destroyed which does not seem possible on Sir J. Larmor's view. The kinetic theory of gases agrees best with the facts when the atoms are regarded as rigid spheres which again is strongly in favour of Sir J. J. Thomson's theory.

This theory therefore may be used as a working hypothesis which enables a mental picture of the atom to be formed. It leaves the nature of electricity and of the æther an open question and is conse-

[1] "The Corpuscular Theory of Matter," 1907.

quently much less fundamental than, for example, Lord Kelvin's vortex ring theory. The negative electrons and the positive sphere may or may not turn out to be modes of motion of the æther; at present we cannot say.

One of the first questions which naturally arises in connection with this theory is, how many negative electrons are there in each atom? This question has been answered approximately by examining the effect of matter on light and Röntgen rays. When electric waves pass over electrons the electrons are acted on by the electric forces in the waves and so emit radiation. This means that the electrons scatter the incident radiation. The amount of radiation scattered by one electron can be calculated on the electromagnetic theory and hence from the amount observed to be scattered by a known amount of matter the number of electrons in the matter can be estimated, the number of atoms in a given amount of matter can be exactly calculated because we know the charge carried by one atom in electrolysis and the total charge carried by the matter. Hence we can get an estimate of the number of electrons per atom. The total energy scattered by a mass containing N electrons is $\frac{8\pi}{3}N\frac{e^4}{m^2}E$, where e is the charge on one electron, m its mass and E the incident energy. This formula is due to Sir J. J. Thomson.

The most recent determination of the energy scattered when Röntgen rays pass through matter is that by Crowther.[2] He finds that the number of electrons per atom of aluminium is 85, which is about three times the atomic weight. Previous experiments of a similar character have given nearly the same result for other elements. It seems very probable therefore that all atoms contain a number of electrons proportional to their atomic weights and not very much greater.

The mass of a negative electron is only one seventeen-hundredth part of that of an atom of hydrogen, so that the negative electrons only account for about one six-hundredth of the mass of any atom. The rest of the mass therefore must be the mass of the positive sphere. According to this theory therefore the mass of matter is not electromagnetic in its origin, for the electromagnetic mass of the

[2] *Proc. Roy. Soc.*, A, Vol. 85, p. 29, 1911.

positive sphere is negligible. This theory therefore does not support the view which is the basis of the "principle of relativity," that all phenomena are electromagnetic in character. The mass and rigidity of the positive spheres are assumed to exist and cannot be explained by electromagnetic forces. There is no reason why the motion of these spheres through the æther should not produce effects capable of being detected and which would enable us to determine the velocity of the earth relatively to the æther. The fact that this has not yet been done does not prove that it is impossible.

According to Sir J. J. Thomson's theory the properties of different atoms are due to the number and arrangement of the electrons in the positive sphere. The problem of the distribution of n electrons in a positive sphere has not been solved and is very complicated, so Sir J. J. Thomson investigated the much simpler problem of the distribution of n electrons in a plane when they are all acted on by forces of attraction proportional to their distances from a fixed point in the plane.

This problem can also be solved experimentally by means of Professor Mayer's floating magnets. The electrons arrange themselves in concentric rings. Thus six give a ring of five and one in the middle. Seventeen give a ring eleven, a ring of five and one in the middle. Thirty-two give rings of fifteen, eleven, five and one in the middle. Forty-nine give rings of seventeen, fifteen, eleven, five and one in the middle.

With two in the middle we get a series of rings containing 8, 12, 16, 19 and 22 electrons respectively and a similar series with three in the middle and so on.

This leads to a very interesting suggestion with regard to the series of elements which have similar properties for example:

Helium, neon, argon, krypton, xenon; hydrogen, lithium, sodium. potassium, rubidium, cæsium; fluorine, chlorine, bromine, iodine.

Sir J. J. Thomson suggests that each element in such a series may be derived from the one before it by the addition of another ring of electrons the arrangement of the inner rings remaining unchanged. This explains the similarity of the properties of the elements in such series.

On this view an atom of bromine is an atom of chlorine with the

addition of one more ring of electrons together with the additional amount of positive electricity required to keep the atom neutral. Sir J. J. Thomson has shown that many of the facts connected with Mendeléeff's periodic law can be explained on this theory.

In the atoms of course the electrons are not really confined to one plane but are distributed throughout the volume of the positive sphere, so that instead of concentric rings of electrons there are concentric spherical layers. An atom of bromine is therefore derived from an atom of chlorine by the addition of one more layer, the inner layers remaining unchanged.

Although the exact solution of the problem of the distribution of n electrons inside a positive sphere is too complicated to be worked out I find that an approximate solution can be obtained without much difficulty, which enables the results of the theory to be compared with the atomic weights of the elements.

Consider an electron having a negative charge e inside a sphere of positive electricity of uniform density of charge ρ per c.c. Close to the electron the electric field is of strength e/r^2, where r is the distance from the electron, so that $4\pi e$ tubes of electric force come out of the electron, if the number of tubes per sq. cm. is taken to be equal to the field strength. Consider one of these tubes of force and let ds be an element of its length and α its cross section at ds. The charge in the length ds is $\rho\alpha ds$, so that

$$F\alpha - \left(F\alpha + \frac{d}{ds}(F\alpha)ds\right) = 4\pi\rho\alpha ds,$$

where F is the electric force along ds. Hence

$$-d(F\alpha) = 4\pi\rho\alpha ds,$$

which gives

$$F_1\alpha_1 - F\alpha = 4\pi\rho\int\alpha ds,$$

where $F_1\alpha_1$ denotes the value of $F\alpha$ at the surface of the electron. This shows that as we go along the tube $F\alpha$ diminishes and when $F_1\alpha_1 = 4\pi\rho\int\alpha ds$ it will be zero and the tube will end. Now $F_1 = e/a^2$, where a is the radius of the electron and $\alpha_1 = a^2/e$, so that $F_1\alpha_1 = 1$, hence $4\pi\rho\int\alpha ds$ from the surface of the electron to the end of the tube is equal to unity. Thus the positive charge in each

tube is $1/4\pi$ so that its volume is $1/4\pi\rho$. The total volume of all the $4\pi e$ tubes is therefore e/ρ. Thus the tubes of force starting from the electron occupy a volume e/ρ and this is true in any case whether other electrons are near or not. Also since every tube of force must end on positive electricity it is clear that the volume e/ρ can only contain the one electron from which the tubes start. Thus when any number of electrons are present each one will be surrounded by its own field which will occupy the volume e/ρ. The positive charge in the volume e/ρ is equal to e, so that if the sphere has a positive charge equal to the total negative charge on the n electrons in it, it will be divided up into n equal volumes, each containing one electron.

The energy in an element of a tube of force is equal to $F^2\alpha ds/8\pi$, and if the tube is slightly distorted this element will still have the same volume and also $(F\alpha)$ will remain unchanged so that the change in the energy in the element will be due to the change in F. The energy will be a minimum when the tube is in equilibrium so that F will be as small as possible and therefore a as large as possible. This means that the tubes tend to become as short as possible, their volumes remaining constant. The effect of this will evidently be to make the field round each electron tend to become as nearly spherical as possible with the electron in the middle.

Consequently to determine approximately the distribution of the n electrons in the positive sphere it is sufficient to find how the sphere can be divided up into N equal volumes, all as nearly spherical as possible and put an electron at the center of each of the n volumes.

When n is large it is easy to see that this requires the electrons to be arranged like the centers of the shot in a pile of shot. Thus with thirteen electrons we should have one in the middle and twelve arranged around it, all at the same distance from it.

Suppose the volume of the field of one electron is v, and let n_1, n_2, n_3, etc., denote the number of electrons in the atoms of a series of similar elements. Each element is formed by the addition of a spherical layer to the one before it and it is clear that all the layers must be of nearly the same thickness if the fields of all the electrons are to be nearly spherical. Consequently if r_1, r_2, r_3, etc.,

denote the radii of the atoms in the series we should expect to have

$$r_2 - r_1 = r_3 - r_2 = r_4 - r_3 = \text{etc.}$$

Let A_1, A_2, A_3, etc., denote the atomic weights and suppose $\beta A_1 = n_1$, $\beta A_2 = n_2$, etc., where β is a constant. Then we have

$$\tfrac{4}{3}\pi r_m^3 = n_m v = \beta v A_m,$$

$$\tfrac{4}{3}\pi r_{m+1}^3 = n_{m+1} v = \beta v A_{m+1}.$$

Hence

$$\left(\frac{4\pi}{3\beta v}\right)^{\frac{1}{3}}(r_{m+1} - r_m) = A_{m+1}^{\frac{1}{3}} - A_m^{\frac{1}{3}} = C,$$

where C is a constant which should be the same for all series of similar elements.

Also $(r_{m+1} - r_m)^3 = v$ approximately, so that

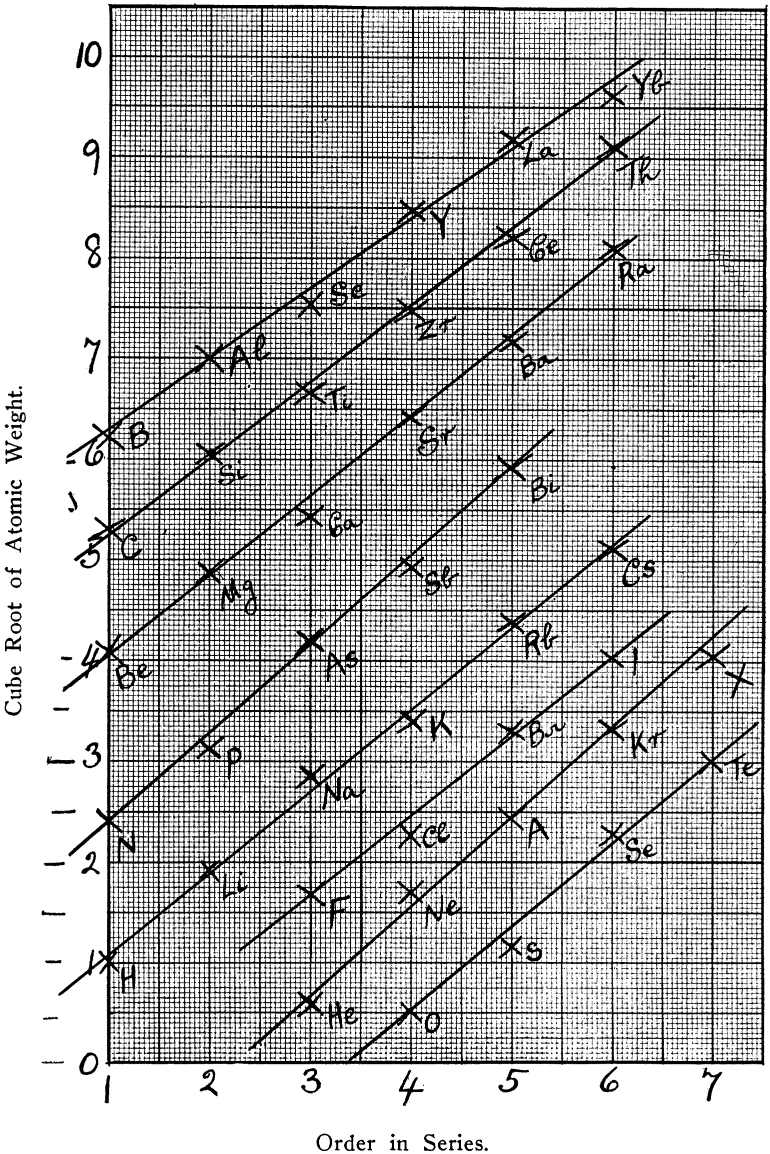
$$\beta = \frac{4\pi}{3C^3}.$$

According to the theory therefore we ought to be able to find the number of electrons per atom from the atomic weights.

In the figure the values of $A^{\frac{1}{3}}$ for series of similar elements are plotted against the order of the elements in the series. For some series a constant has been added to the values of $A^{\frac{1}{3}}$ to prevent the different lines falling too close together. It will be seen that the values of $A^{\frac{1}{3}}$ for each series fall nearly on straight lines and that the different lines are nearly parallel. This shows that $A_{m+1}^{\frac{1}{3}} - A_m^{\frac{1}{3}} = C$ is nearly constant, as was to be expected from the theory. The mean value of C is 0.81. Hence we get $\beta = 8$ so that the number of electrons per atom comes out 8 times the atomic weight in all cases.

This estimate agrees as well as could be expected with the numbers deduced from the optical properties of the elements which might be expected to be too low.

We have assumed that the electrical density of the positive spheres is uniform so that the approximate agreement of the atomic weights with the theory confirms this assumption. It is easy to see that the arrangement of the electrons in the positive sphere is not affected by a change in the size of the sphere provided its density remains uniform and its total charge the same as before. It is



possible therefore that the addition of new layers increases the density of the positive spheres instead of increasing their size. If

this were so the calculation of β given above would not be affected as can be easily seen.

The equation $(4\pi/3\beta)^{\frac{1}{3}} = A_m^{\frac{1}{3}} - A_{m-1}^{\frac{1}{3}}$ gives

$$A_m = \left(A_1^{\frac{1}{3}} + (m-1)\left(\frac{4\pi}{3\beta}\right)^{\frac{1}{3}}\right)^3.$$

This equation enables the atomic weights of a series of similar elements to be approximately calculated if that of the first in the series is known. For example, if we take $A_1 = 1$ we obtain the following numbers:

m	A_m	
1	1	H = 1
2	6	Li = 7
3	18	Na = 23
4	40	K = 39
5	77	Rb = 85
6	129	Cs = 133

If we take $A_1 = 9$ we obtain the following numbers:

m	A_m	
1	9	Be = 9
2	24	Mg = 24
3	51	Ca = 40
4	92	Sr = 87
5	150	Ba = 137
6	230	Ra = 226

It will be seen that the numbers given by the approximate formula deduced from Sir J. J. Thomson's theory agree approximately with the atomic weights. I think this must be regarded as strong evidence that there is a considerable element of truth in the theory.

I believe that this is the first time that a definite theory of atomic structure has been worked out sufficiently to enable a comparison between theoretical results and the known atomic weights to be made.

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